Dynamic Simulation and Liquid Level Control in A Pure Capacity System (2 Tanks in Series)

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Abstract

The open loop experiment of pure capacity system for 2 liquid tanks in series has been successfully done in laboratory[1]. Two square tanks were designed and arranged in series for investigation in laboratory. The water stream with its volumetric rate of $f_i(t)$ [cm^3/min] was flowed to the 1st tank (Tank-1). The liquid in Tank-1 was then be pumped to the 2nd tank (Tank-2), with its volumetric rate of $f_1(t)$ [cm^3/min]. The volumetric rate of $f_1(t)$ can be adjusted by changing the voltage of the pump, m(t) [volt]. This study has proposed the liquid level control configuration of 2 tanks in series system. In this work, the water volumetric rate of $f_i(t)$ was considered as a disturbance. The liquid level of Tank-1 $h_1(t)$ was kept constant by manipulating the voltage of the pump $m(t)$. The output volumetric rate of Tank-2 $f_2(t)$ was chosen as a manipulated variable to control the liquid level of Tank-2 $h_2(t)$. The P-only-control was implemented to control the liquid level of Tank-1 and PI-control to control the liquid level of Tank-2. Control parameters were tuned by trial and error with minimum integral criteria. The controller gain (K_c) for liquid level control of Tank-1 (LC-1) was found -50 volt/cm, and for Tank-2 (LC-2) was -500 cm^2/minute. The integral time (τ_I) for LC-2 are 2 minute and 0.1 minute. In order to examine the control configuration, the input water volumetric rate disturbance (with amount of ±14%) was made based on step function. The closed loop dynamic simulation using computer programming has been done. The developed mathematical model of liquid level control in this system was solved numerically. Scilab software was chosen to examine such mathematical model. Integral of the absolute value of the error (IAE) for LC-1 and LC-2 were 6.1 and 3.6, respectively. This study revealed that the proposed control configuration with its tuning parameters gave a stable response to a change in the input water volumetric rate.

Keywords: Closed Loop; Dynamic Simulation; Open Loop ; PI Control; Pure Capacity; Step Function;.

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1. Introduction

Pure capacity system is also known as an integrating system and widely used in chemical process industries. The pure capacity or integrating system is defined as a system with the transfer function equals to $1/s$[7]. This system can be found in the multi-capacity processes such as non-interacting-tank and interacting-tank. This pure capacity process consists of two (or more) tanks arranged in series, where the fluid from one tank is flowed to the other tank by means of a transfer pump. The input disturbance changes (e.g. the inlet volumetric rate, and the pump's energy) strongly effect to the liquid levels in all tanks. The implementation of automatic liquid level control is therefore very important.

Some experiments in field of process dynamic and control have been done in laboratory. The open loop liquid level and temperature dynamic in a non-interacting-tank system with recycle stream has been done[4], [5]. Also, the design of process control configuration for non-interacting-tank system by using quantitative analysis of Relative Gain Array (RGA) has been presented by Hermawan, Y.D. *et al.* [3]. This research was then continued with study on the dynamic simulation and control in a non interacting tank[2]. Recently, the open loop experiment of 2 tanks in series as a pure capacity system has been successfully done by Hermawan, Y.D. *et al*. in 2014 [1]. The study on closed loop dynamic simulation and liquid level control in 2 tanks in series will be done in this work. The closed loop responses of liquid level control configuration will also be explored.

2. Experimental

Fig. 1 shows the experimental apparatus setup[1]. Water was used as a fluid in this work. As shown in **Fig. 1**, No 1 and No 2 are Tank-1 and Tank-2 respectively that arranged in series. The inlet water flowrate to the Tank-1 $f_i(t)$ could be adjusted by valve (No 7a). Water from the Tank-1 was then flowed to the Tank-2 by means of a transfer pump (No 3a). The pump's flowrate could be adjusted by means of an electric volt regulator (No 4). Thus, the outlet water flowrate from Tank-1, $f_1(t)$, was influenced by the electric voltage of pump $m(t)$. But, the water outlet from Tank-2 depended on the liquid level in Tank-2. The steady state parameters of 2 tanks in series system had been found experimentally in laboratory, and they are shown in **Table 1**[1].

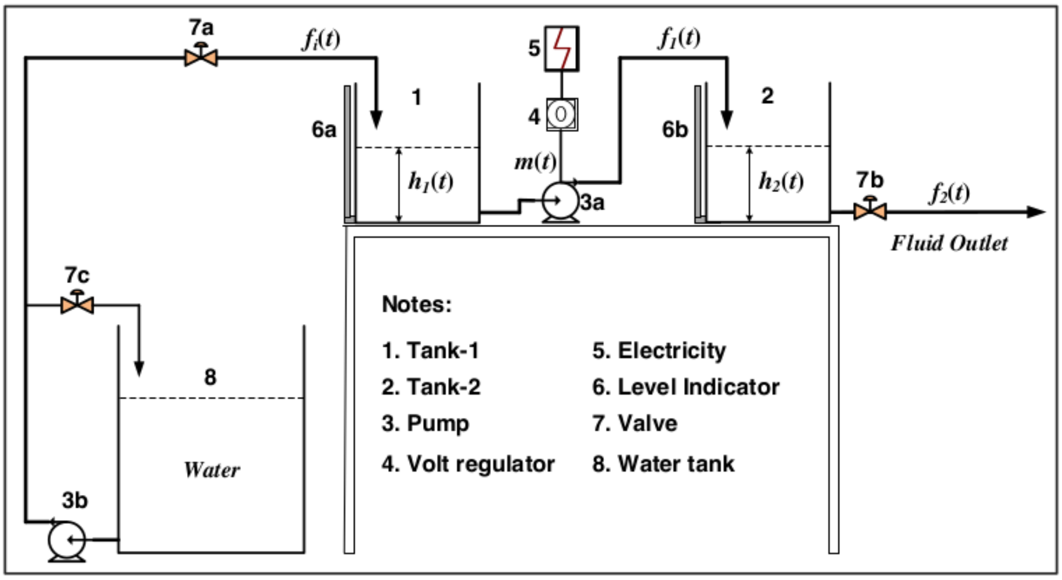

Fig. 1. The experimental Apparatus Setup[1].

Mass balance of Tank-1 can be written as follows:

$$\frac{dh_1(t)}{dt} = \left(f_i(t) - f_1(t)\right) / A_1 \tag{1}$$

The output flowrate of the Tank-1 $f_1(t)$ depends on the pump's energy, and is written as follows:

$$\tau_p \frac{df_1(t)}{dt} + f_1(t) = K_p\, m(t) \tag{2}$$

Mass balance of Tank-2 is:

$$\frac{dh_2(t)}{dt} = \left(f_1(t) - f_2(t)\right) / A_2 \tag{3}$$

Table 1. Steady State Parameters[1].

No	Variable	Steady State
1	Volumetric flowrate of stream-i, f_i [cm^3/minute]	14,125.76
2	Volumetric flowrate of stream-1, f_1 [cm^3/minute]	14,125.76
3	Volumetric flowrate of stream-2, f_2 [cm^3/minute]	14,125.76
4	Pump's voltage, m [volt]	63
5	Liquid level in Tank-1, h_1 [cm]	10
6	Liquid level in Tank-2, h_2 [cm]	10
7	Pump process gain, K_p [cm^3/(minute.volt)]	224.22
8	Pump process time constant, τ_p [minute]	1
9	Cross-sectional area of Tank-1, A_1 [cm^2]	400
10	Cross-sectional area of Tank-2, A_2 [cm^2]	400

Liquid level control configuration of this system is illustrated in **Fig. 2**. There are 2 couples of CV-MV in the control configuration as shown in **Table 2**; they are liquid level controller for Tank-1 (LC-01) and liquid level controller for Tank-2 (LC-02). Since the Tank-1 with its pump is as a pure capacity system, the P-only control is enough for controlling its level. But, PI control would be implemented for controlling the liquid level of Tank-2. The control parameters for 2 level controllers were tuned by trial and error with minimum integral criteria and listed in **Table 2**. The pump's voltage $m(t)$ and the outlet flowrate of Tank-2 $f_2(t)$ were chosen as the manipulated variables (MV) to control the liquid levels for Tank-1 and Tank-2, respectively.

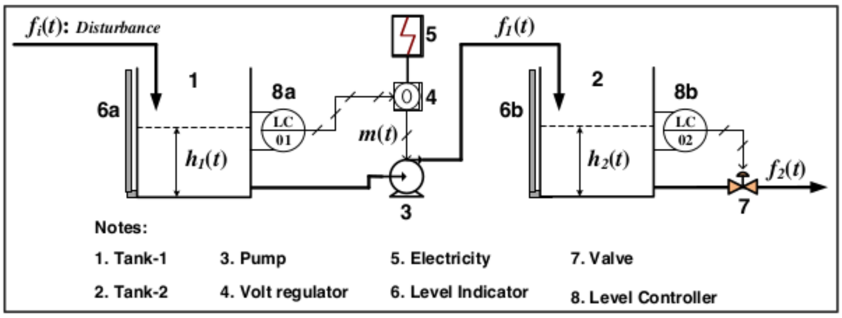

Fig. 2. The Liquid Level Control Configuration of 2 Tanks in Series.

Table 2. Couples of CV-MV and Control Parameters

Controller	CV	MV	Control Type	PI Control Parameters K_c	PI Control Parameters τ_I	IAE
LC-01	$h_1(t)$	$m(t)$	P	-50 [volt/cm]		6.1

LC-02	$h_2(t)$	$f_2(t)$	PI	-500 [cm^2/minute]	0.1 [minute]	3.6

Manipulated variables for 2 level controllers are as follows:

Manipulated variable of LC-01: $m(t) = \overline{m} + K_{c1} e_1(t)$ (4)

where: $e_1(t) = h_1^{SP} - h_1(t)$ (5)

Manipulated variable of LC-02: $f_2(t) = \bar{f}_2 + K_{c2} e_2(t) + \frac{K_{c2}}{\tau_{I2}} \int e_2(t) dt$ (6)

where: $e_2(t) = h_2^{SP} - h_2(t)$ (7)

Integral of the absolute value of the error (IAE) for both controllers can be calculated as bellows[6]:

IAE of LC-01: $IAE_1 = \int_0^\infty e_1(t) dt$ (8)

IAE of LC-02: $IAE_2 = \int_0^\infty e_2(t) dt$ (9)

The developed mathematical model of the liquid level control configuration system was solved numerically with the easiest way of explicit Euler. The Scilab software was chosen to carry out the closed loop dynamic simulation. In order to examine the performance of the developed level control configuration, the input mass disturbance load was made based on step function. The input volumetric rate of Tank-1 $f_i(t)$ was changed ±14% from its initial value. The closed loop responses of control system to a change in the mass disturbance load will then be explored in this work.

3. Results and Discussion

Fig. 3 shows the closed loop responses to a change in the inlet volumetric rate of Tank-1 (f_i). Solid lines in **Fig. 3** are the closed loop responses to a step-increase change in the inlet volumetric rate of Tank-1 (f_i). The volumetric rate f_i was increased by an amount of 2000 cm^3/minute (from 14,125 cm^3/min to 16,125 cm^3/min). As can be seen from **Fig. 3**, all controlled variables oscillate and finally return to its set point. The liquid level of Tank-1 (h_1) oscillates, dies out, and finally backs to its set point at time about 12 minutes (**Fig.3.a**). The pump's voltage (m) is manipulated to maintain the liquid level in Tank-1 at its set point (**Fig. 3.b**). Finally, the pump's voltage achieves new steady state value of 71.8 volt at time equals 12 minutes (**Fig. 3.b**). The characteristic change of Tank-1 propagates to the next tank, i.e. Tank-2. The dynamic behaviour of liquid level of Tank-2 is similar with that in Tank-1. However, the liquid level of Tank-2 can be returned to its set point of 10 cm at time equals 12 minutes (**Fig. 3.c**). The output volumetric rate of Tank-2 (f_2) is manipulated to keep the liquid level of Tank-2 constant. The volumetric rate f_2 rises a new steady state value of 16,125 cm^3/min at time equals 12 minutes (**Fig. 3.d**).

Dashed lines in **Fig. 3** are the closed loop responses to a step-decrease change in the inlet volumetric rate of Tank-1 (f_i). The volumetric rate f_i was decreased by an amount of -2000 cm^3/minute (from 14,125 cm^3/min to 12,125 cm^3/min). Since the input volumetric rate of Tank-1 decreases, it is understandable that the liquid level in Tank-1 (h_1) descends first, and then it can be returned to its set point at time about 12 minutes (**Fig. 3.a**). In order to keep the liquid level h_1 constant at its set point, the volumetric rate of f_1 should be decreased. This is done by manipulating the pump's voltage (m). Finally, the pump's voltage achieves new steady state value of 54.2 volt at time equals 12 minutes (**Fig. 3.b**). Again, response of liquid level h_2 is similar with that of liquid level h_1. The liquid level h_2 can finally be backed to its set point at time about 12 minutes (**Figure 3.c**), and the volumetric rate f_2 drops to a new steady state value of 12,125 cm^3/min at time equals 12 minutes (**Fig. 3.d**). The IAEs of LC-1 and LC-2 has also been found; they are 6.1 and 3.6, respectively, as listed in **Table 2**.

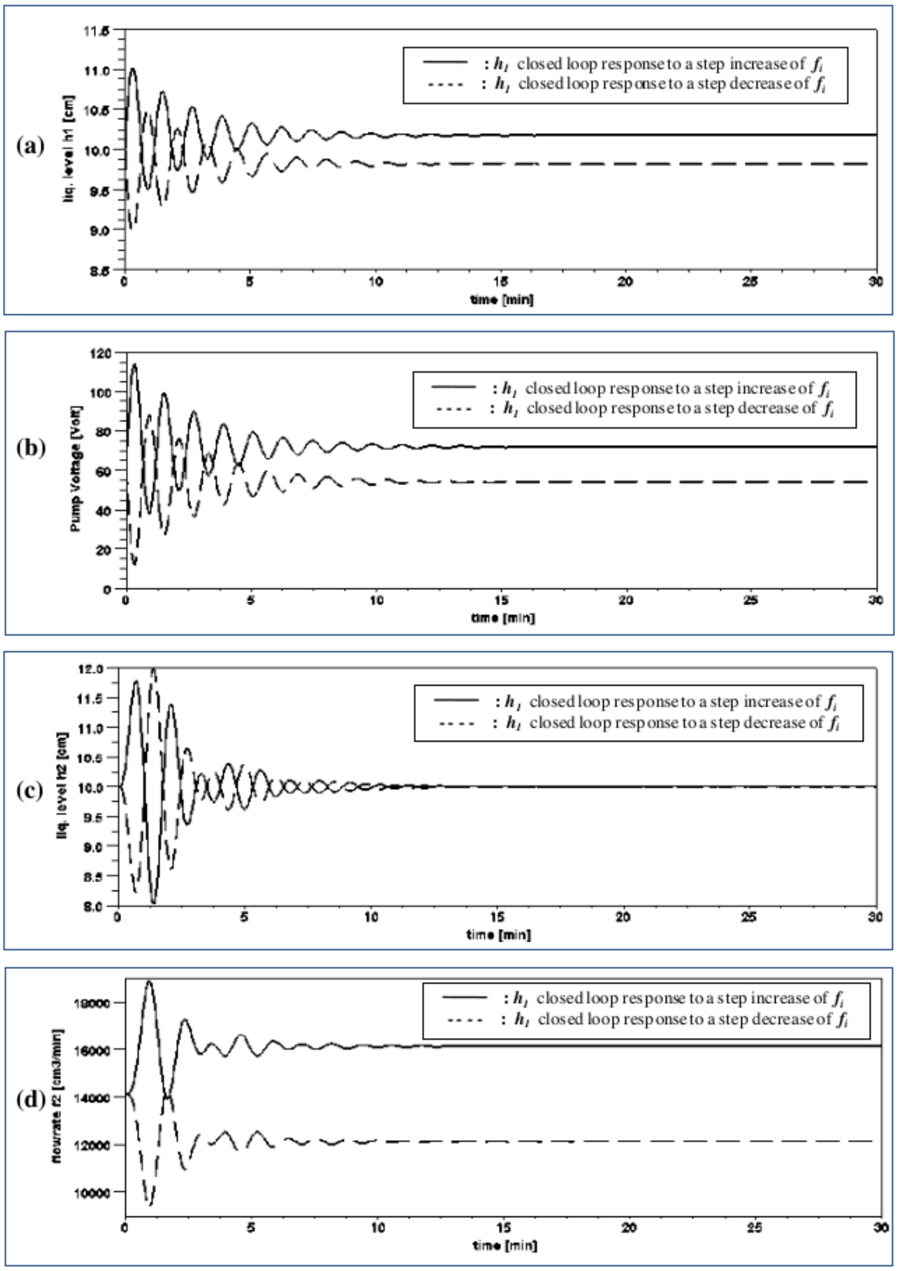

Fig. 3. The Closed Loop Responses to a Change in the Inlet Fowrate f_i(t): (a) Liquid Level of Tank-1, (b) Pump's Voltage, (c) Liquid Level of Tank-2, (d) Outlet Flowrate of Tank-2.

4. Conclusion

This paper has discussed dynamic simulation and liquid level control in a pure capacity system (2 tanks in series). The developed liquid level control configuration has been examined through rigorous dynamic simulation. As can be seen from our closed loop dynamic simulation, the control configuration with its P-control and PI-control parameters gives stable responses to a change in the input mass disturbance load. This study also reveals that by tuning the appropriate control parameters, stable and fast responses can be achieved.

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Nomenclature

$A_{1,2}$	cross sectional area of Tank 1,2 [cm^2]
$e_{1,2}$	error for LC-01 and LC-02 [cm]
$f_{i,1,2}$	volumetric rate of stream i, 1, 2 [cm^3/minute]
$h_{1,2}$	liquid level of Tank 1, 2 [cm]
h_1^{SP}	set point of liquid level of Tank-1 [cm]
h_2^{SP}	set point of liquid level of Tank-2 [cm]
K_p	pump's process gain [cm^3/(minute.volt)]
K_c	proportional gain of controller: K_{c1} [volt/cm] ; K_{c2} [cm^2/minute]
m	pump's voltage [volt]
t	time (minute)
$V_{1,2}$	liquid volume of Tank 1,2 (cm^3)
Greek letters	
ρ	liquid density (gr/cm^3)
τ_I	integral time constant (minute)
τ_p	pump's time constant (minute)

References

[1] Hermawan, Y.D., Kholisoh, S.D., Hamdani, A.F., and Puspita, D.D. Process Dynamic in A Pure Capacity System (2 tanks in series), *Seminar Rekayasa Kimia dan Proses (SRKP) 2014*, Department of Chemical Engineering, Universitas Diponegoro, F-02-1 – F-02-6, (*in Indonesian*).

[2] Hermawan Y.D. Dynamic Simulation and Control in A Non-Interacting-Tank System, *19th Regional Symposium on Chemical Engineering (RSCE) 2012*, Department of Chemical Engineering, Institut Teknologi Sepuluh Nopember (ITS) Surabaya, November 27-28, 2012, Bali, Indonesia: B-27-1 – B-27-6.

[3] Hermawan Y.D., Suksmono Y., Narno Putra R.M., and Puspitasari M. Design of Process Control Configuration for Non-Interacting-tank System by Using Quantitative Analysis of Relative Gain Array, *Seminar Nasional Teknologi Simulasi (TEKNOSIM) 2010*, Department of Mechanical Engineering and Industry, Universitas Gadjah Mada: 75 – 8 (*in Indonesian*).

[4] Hermawan, Y.D., Suksmono, Y., Dewi, D.U., and Widyaswara, W. Liquid Level Dynamic in A Non-Interacting-Tank System with Recycle Stream, *Seminar Nasional Teknik Kimia "Kejuangan"* 2010, Department of Chemical Engineering, Universitas Pembangunan Nasional "Veteran" Yogyakarta: D08-1 – D08-6 (*in Indonesian*).

[5] Hermawan, Y.D., Suksmono, Y., Sulistyowati, E., Cicilia, E., and Aisiyah, D.S. Temperature Dynamic in A Non-Interacting-Tank System with Recycle Stream, *Seminar Nasional Teknik Kimia "Kejuangan"* 2010, Department of Chemical Engineering, Universitas Pembangunan Nasional "Veteran" Yogyakarta: D10-1 – D10-6 (*in Indonesian*).

[6] Smith, C.A., and Corripio, A.B. *Principles and Practice of Automatic Process Control*, John Wiley & Sons, Inc., USA, 1997, p. 321 - 329.

[7] Stephanopoulos, G. *Chemical Process Controll: An Introduction to Theory and Practice*, PTR. Prentice-Hall, Inc., A Simon and Shuster Company, New Jersey, 1984, p. 173 - 179. & p. 302 - 306.

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